ASPECTS OF THE PERTURBATION BY b_{10}

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Abstract

Following the proposal to mix the US and KEK magnets to overcome the consequences a too large b_{10} in error table v2.0, a crash study was initiated at CERN. Its results show that the b_{10} of table v2.0 is potentially dangerous and that it must be reduced below 0.1 units.

1 INTRODUCTION

The effect of $b_{10} = 0.25$ units was considered from different point of views: feed-down on lower-order multipoles, dynamic aperture at 10^5 turns and frequency map analysis.

2 FEED-DOWNS OF b_{10}

As noted by J. Shi'in his study of global correction [1] and by S. Fartoukh [2], b_{10} most likely acts by feed-down to lower orders. It is in fact easy to calculate by hand the feed-down due to the off-axis orbit caused by the crossing angle. In Table 1, we assume a beam displacement of 6 mm in the quadrupole (while the real displacement ranges from 4.5 mm to 7 mm at the entrance and exit of the triplet). It is

n	$< b_n >$	$d(b_n)$	$\sigma(b_n)$	$< a_n >$	$d(a_n)$	$\sigma(a_n)$
3	0+**.01**	.51	1.00	0-**.01**	.51	1.00
4	0+**.04**	.29	.57	0	.29	.57
5	0+**.17**	.19	.38	0+**.17**	.19	.38
6	0+**.49**	.50	.19	0	.10	.19
7	0+**.92**	.05	.06	0-**.92**	.05	.06
8	0+**1.12**	.02	.03	0	.02	.03
9	0+**.79**	.01	.01	0+**.79**	.01	.01
10	.25	.03	.01	0	.01	.01

Table 1: KEK Table v2.0 with the feed-downs of $< b_{10} >$ added to the systematics, for an horizontal displacement of +6 mm; the fields are expressed in units at 17 mm

clear that a systematic $< b_{10} >= .25$ produces lower-order perturbations often significantly larger than those due to the design and uncertainties. Just from inspection and knowing that $< b_6 >$ is the second limit after $< b_{10} >$ [3], it is easy to conclude that $< b_{10} >$ shall not exceed 0.1 or even less.

3 INFLUENCE OF b_{10} ON THE DYNAMIC APERTURE

Mixed or unmixed layouts of the triplet quadrupoles were tested for dynamic aperture. This work, carried out by F. Schmidt [4] was done in the following way: the uncertainty is added to the systematic imperfection in such a way as to maximize it; all quadrupoles are then allocated the same multipole errors calculated in the above mentioned way. Tracking is carried out over 10^5 turns, 6D. The random part of the errors is not included to disentangle the pure effect of systematic b_{10}. Furthermore it is known [3] that random b_6 is the next limit after b_{10} and that the US and KEK tables show very different values for random b_6 while they would be expected to be the same; they have indeed be equalized in the latest version of the tables. It is very clear on figure 1

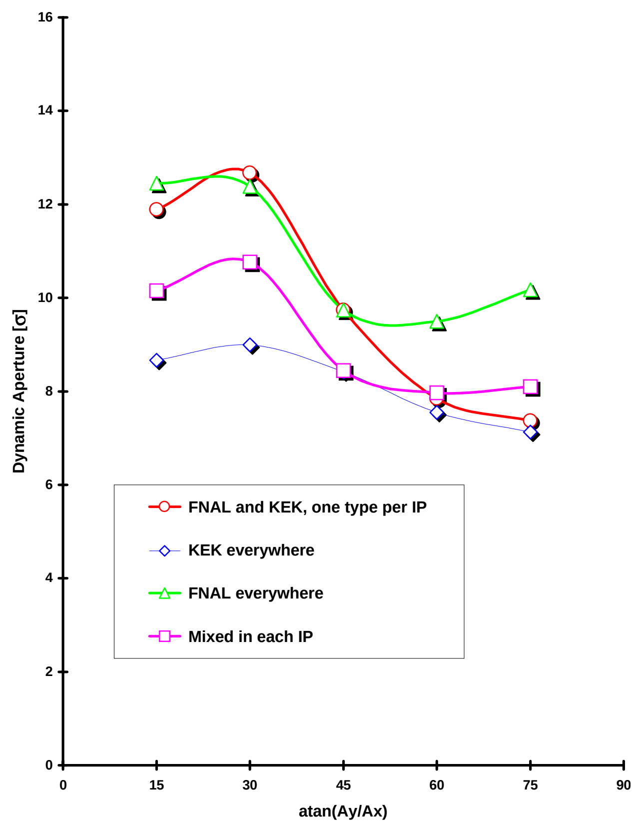

Figure 1: Dynamic aperture versus initial amplitude ratio for various triplet scenarios

that $b_{10} = .25$ causes a loss of dynamic aperture of 2σ, i.e. 20%, **whatever the scenario, mixed or not mixed**.

4 SIGNATURE OF b_{10} ON FREQUENCY MAPS

Another approach to the question is the qualitative inspection of the frequency maps calculated for the various scenarios. This work was carried out by I. Papaphilippou [5]. A very large number of initial conditions, characterized by the radius of the circle in the x, y plane are tracked for 1000 turns, 4D. The tunes are calculated over the last 100 turns and displayed as a function of amplitude. The range of amplitudes extends to 15σ, to take into account both the short tracking time and the missing 3rd degree of freedom. Here again, only the systematic and uncertain imperfections are considered. In the scenario where KEK magnets are installed in all IR's, the perturbation of the frequency space is very pronounced. 10σ particles are trapped by the (1,-1) sub-resonance. From experience, these particles are expected to be unstable. If KEK magnets are installed in half of the IR, the footprint is smaller though unstable 10σ particles are still expected. In the mixed scenario, the footprint shrinks drastically for medium amplitude particles. However large amplitude particles are still attracted by the (1,-1) resonance much more than in the case where b_{10} systematic vanishes (FNAL only).

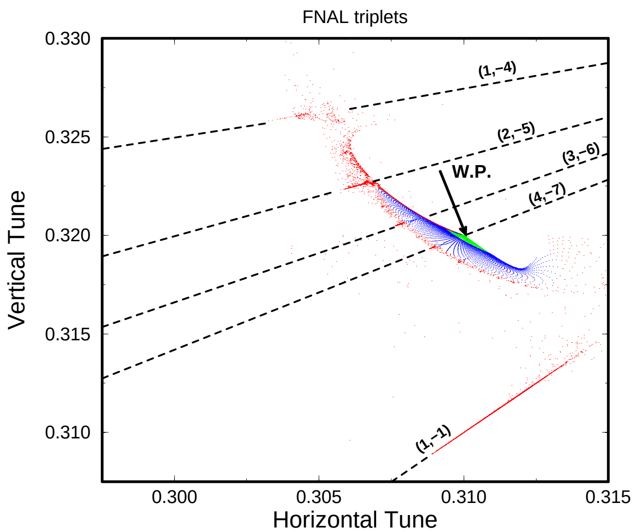

Figure 2: Frequency map for FNAL triplets only

Given two important missing ingredients in the tracking: the modulation of the parameters and the beam-beam interaction, it would be risky, at this stage, to accept such a distortion of the dynamics. Furthermore, the effect are systematic and therefore the phase advance between the IR's matter. We do not know whether the present situation is a best or a worst case. It will not be maintained anyway as the tune split is changing to maximize the dynamic aperture at injection.

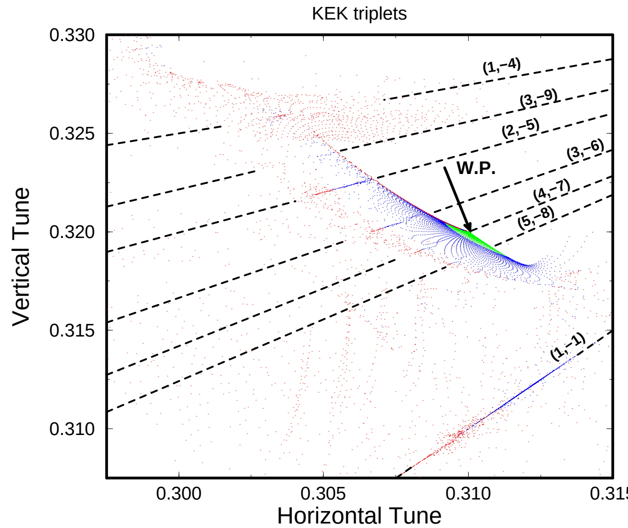

Figure 3: Frequency map for KEK triplets only

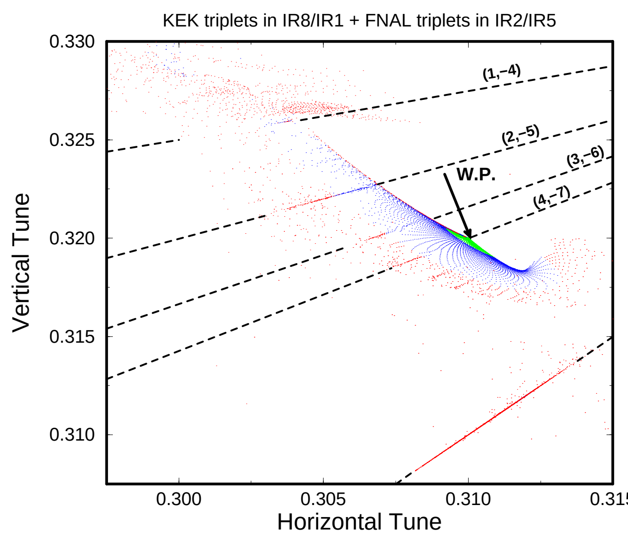

Figure 4: Frequency map for FNAL and KEK triplets not mixed

5 CONCLUSION: TARGET b_{10}

If we assume that the dynamic aperture is only related to b_{10}, it is possible to scale exactly b_{10} to recover the 2σ loss. Because of the crossing angle, we further have to assume that either b_{10} acts as such or that it acts through a feed-down, say b_6. The scaling is such that, if b_n is multiplied by α, the dynamic aperture is divided by $\alpha^{1/(n-2)}$. To recover the 20% loss, the scaling shows that $b_{10} = .25$ should be decreased by a factor of 4, i.e. the target $b_{10} = .06$. This value seems reasonable if compared to the measured harmonics of all FNAL models which are all weaker [6]. This estimate is of course rough and tracking would be required if the target b_{10} would be difficult or expensive to reach. It is however consistent with the requirement stemming from the calculation of feed-downs.

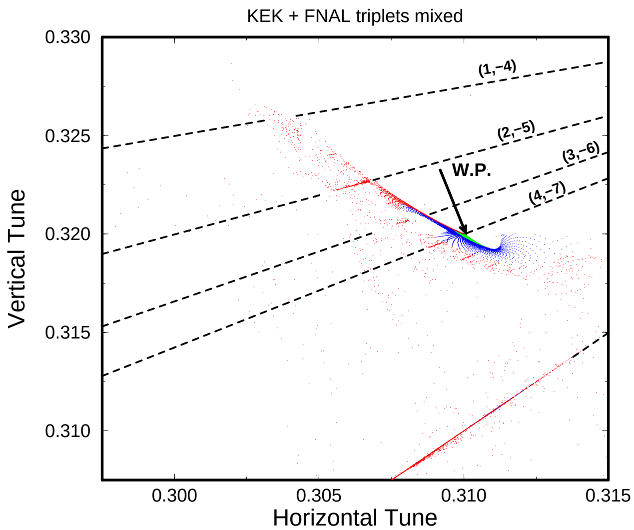

Figure 5: Frequency map for the mixed case

6 REFERENCES

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[2] S. Fartoukh, private communication, Cern, April 1999.

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[4] H. Grote and F. Schmidt, 'LHC dynamic aperture studies at collision energy including beam-beam and triplet errors', Cern 1999, to be published.

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[6] G.L. Sabbi *et al.*, PAC99.